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## CHARM 2010: Experiment Summary and Future Charm Facilities

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The CHARM 2010 meeting had over 30 presentations of experimental results, plus additional future facilities talks just before this summary talk. Since there is not enough time even to summarize all that has been shown from experiments and to recognize all the memorable plots and results, this summary will give a few personal observations, an overview at a fairly high level of abstraction.

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### 1. Introduction

This CHARM 2010 at IHEP in Beijing is only the 4th International Workshop on Charm Physics! The previous meetings were held in 2006 here at IHEP (Beijing), in 2007 at Cornell University (Ithaca, NY); and in 2009 in Leimen, Germany. Over 30 presentations of experimental results were presented here before the future facilities talks. Clearly, there is not enough time even to summarize all that we have seen from experiments, to recognize all the memorable plots and results - tempting as it is to reproduce the many clean signals and data vs theory figures, the quantum correlations plots, and the  $D$ -mixing plots before and after the latest CLEO-c data is added. So, this review will give only my personal observations, exposing my prejudices and my areas of ignorance, no doubt. This overview will be at a fairly high level of abstraction - not re-showing individual plots or results. I ask the forgiveness of those who will have been slighted in this way - meaning all the presenters.

### 2. Renewed Interest in Charm Now

Rereading the text on the CHARM 2010 first bulletin, you miss what I think is the most profound hot topic in charm physics today, the observation of charm mixing in the neutral  $D$  meson system, the possibility of this being due to new physics, and of the resulting need to look for  $CP$  violation there.

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Not since the discovery of charm and its immediate impact (belief in quarks for real!) has charm had so much interest. This current interest is focused on the size of  $D^0$  mixing. Given its size, mixing in the  $D^0$  system could be due to new physics. If so, observation of  $CP$  violation in this mixing would be a demonstration that the observed large mixing is due to physics beyond the standard model. Before, standard-model mixing in charm was thought to be too small to be interesting. However, this small background from standard-model effects was coming to be seen as a plus before large mixing was observed (relative to  $B$  mesons where the standard-model mixing is now seen as an annoying background to any signal for new physics).

More fundamentally, charm is the only up-type quark with mixing possible, a unique sensitivity to beyond-standard-model physics. Models with minium flavor violation have been made popular due to the good agreement between measurements with kaon and bottom mesons and standard-model predictions (ignoring some less than or about  $3\sigma$  "tensions").

### 3. Experiment Presentations and Their Lessons

We have seen truly impressive numbers of events in plots. Note that we often need the pressure of such copious data to force us to think creatively about underlying physics, to change our prejudices. I remember well how increased data forced E791 collaborators in Rio de Janeiro to propose S-wave resonances (sigma and kappa) to explain the otherwise unfittable Dalitz-plot decay distributions - though in hindsight, earlier data sets had shown evidence of the same need, just not as dramatically. Similarly, data forced FOCUS to see the interference with the S-wave under the  $K^*$  in  $D$  semileptonic decays.

At the same time, we should not forget the lesson cited by Will Johns who remembered how FOCUS "learned more about the realities of the higher-statistics environment".<sup>1</sup> In my experience these realities have included how to take, manage, and analyze the added data - as well as solving physics problems about which the new data may cut out.

Is the disagreement at high  $q^2$  between the LQCD form factors and data trying to tell us something important?

Many results presented at CHARM 2010 are the first such observation or first such measurement - even now in this arguably mature field! Think of:

- New hadronic, radiative, and semileptonic decay modes
- New excited states of charm mesons
- Wide resonances, visible above background with enough data
- Form factors for Cabibbo-suppressed  $D$  decays
- $A_{CP}$  measurements in new decay modes; so far, all consistent with no  $CP$ -violating asymmetry

A surprising number of new results, even among the most interesting new results, have systematic errors which are significantly smaller than the statistical errors -

even from the full CLEO-c, BaBar, or Belle data sets. So, the case for new facilities is very strong on that basis. There is room and utility for much more data.

More data (and more analyses of existing data) are also needed to help reinforce or remove states from the growing list that need to be explained, and to see additional decay modes of states already indicated - even those multiply confirmed. We have all been uncomfortable with the idea that QCD would only choose to make states of quark-antiquark pairs and three quarks of different color. Yet, we seem to be forced against our will to accept other states that we have every reason to believe must exist. On the other hand, it is unlikely that every newly-observed state will survive an onslaught of new data. Possible states near thresholds need to be tested against other explanations: e.g., the possibility of fluctuations in threshold-enhancement-shaped backgrounds and/or fluctuations of backgrounds otherwise incompletely modeled as phase-space shaped.

With the LHC really just starting its turn-on, we are getting a whiff of what may lie ahead from ATLAS, CMS, LHCb, and ALICE. Nevertheless, it has been useful for charm data that the LHC turn-on has been slower than some optimists have expected. This may be our only chance to see the low- $p_t$  production region at 7 TeV. We will have to see how charm-physics goals fit into LHC "full-luminosity" trigger menus.

In spite of all the exciting things we have seen at CHARM 2010, there are important things we have not seen, things that are sorely missed. For example, we have not seen any detailed analyses of the systematic errors in measurements with an extrapolation into the next generation of experiments. Just how far will we be able to push mixing and  $CP$ -violation measurements before we hit a wall of systematic uncertainty? Of course, we will need to experience the additional real data to be certain about this. However, knowing the likely-most-productive modes and avenues to pursue first is always useful. Will techniques have to change to stay competitive? Will we be able to use 10 times more data? 100 times more?

#### 4. An Alert

Many of the results we have seen have been the result of a tour de force - "an army of researchers working for a couple of years" (David Asner).<sup>1</sup> There is concern about the future of doing charm physics, even with new facilities replacing or upgrading old ones. Let me emphasize, however, that the additional data should allow new analyses to be done, new questions to be asked. The "golden times ahead" proclaimed by Ulf Meissner<sup>1</sup> for BEPCII and FAIR - and I would add others - will not be automatic.

Bring the new data on! Force us to think harder.

#### 5. If $CP$ Violation is Observed in Charm Decays, ...

If observed,  $CP$  violation in charm mixing will be a "game-changer" (forcing paradigm change). Motivation for charm physics will increase beyond the often

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cited justification of helping to understand or certify  $B$ -physics applications ("to the rescue" per Jernej Kamenik<sup>1</sup>).

## 6. Comments on Charm Production

Is the color-octet model on its way out as a major source of charm production? It was proposed as an explanation of the historic theory underestimate of the observed production of charmonium and open charm. The model has detailed predictions for polarization of charmonium, predictions which have not been born out by data. To be viable, it also should have had a universality that has not been seen in charm production at HERA and the Tevatron.

I have always been uncomfortable with the appearance of an easy acceptance of any suggested correction to theory that increased cross-section predictions. Which enhancements of the simplest calculations will survive? What will provide universality in matrix elements, and correctly describe onium polarization as a function of  $p_t$ ? Are next-to-leading-order (NLO) and relativistic corrections enough to explain earlier cross-section discrepancies? To flip the size and sign of charmonium polarization? Joan Soto stated that "Important discrepancies with experiment have been resolved";<sup>1</sup> for example, the factor of two in the NLO prediction with respect to the leading-order. However, will the next-to-next-to-leading-order (NNLO) contribution really be negligible on this scale? Theory errors, even before estimating NNLO, etc. remain too large to have confidence yet. Of course, we also want to see resolution of the experimental situation in polarization measurements within CDF (current and earlier) and with DZero.

## 7. Spectroscopy: Hidden Charm and Other Spectroscopy

There is apparent progress since the last CHARM symposium in terms of the observation of various states, both for added decay modes and new states. However, is there any real progress in understanding? Questions in spectroscopy are multiplying still, though some patterns may be appearing. At the same time, charm is providing input to help understand light-meson spectroscopy. A personal favorite of mine is the use of charm decay as a source of information on low mass (e.g., scalar) mesons. Also, charm decays provide clean laboratories for the spectroscopy of excited kaon states. Many of the new states still require confirmation or more precise mass and width measurements. As more data become available from LHCb and from a future Super- $B$  factory, analyses similar to the ones presented here can further elucidate light-meson spectroscopy.

## 8. Fermilab as a Charm Facility

Just prior to this review, motivations and plans were presented for future facilities for charm physics experiments. I will not repeat or summarize these reports now. However, I should probably comment on the situation at Fermilab since it is not otherwise reported.

For now, the only new Fermilab data on charm physics continues to come from CDF and DZero at the Tevatron Collider. The current data taking, Run II, is scheduled to end in September, 2011. However, there is a proposal to extend Run II for three more years, through September of 2014. The US Particle Physics Program Prioritization Panel, P5, just considered this proposal and is to give its recommendation to the High Energy Physics Advisory Panel (HEPAP) on October 26. This is just one more of the hurdles which will have to be surmounted along a possible path to approval. HEPAP will make its comments in transmitting the report to the Department of Energy, and funding may appear in the President's budget for the next fiscal year, which will be public in February, 2011.

Fermilab has asked for approval of a plan which requires additional funding for a Run II extension to happen - so as not to jeopardize other programs currently funded nor to unduly delay the approved program at the High Intensity Frontier. Stay tuned.

There are two other options for future charm physics experiments at Fermilab being discussed:

- Proposal Number 986 - "Medium-Energy Antiproton Physics with The Antiproton Annihilation Spectrometer (TApAS)"<sup>2</sup>
- A new fixed target experiment using the high-energy Tevatron beam<sup>3</sup>

The first is a serious proposal, submitted to Fermilab and scheduled for review by the Fermilab Physics Advisory Committee (PAC) at its meeting, November 4-6. The second is only an attempt to keep alive the possibility of a future Tevatron experiment. Dan Kaplan is spokesperson for the former, serious proposal; Alan Schwartz and I have led the discussion of the latter. Both options require use of facilities scheduled for decommissioning and/or reuse for other programs at Fermilab. Again, stay tuned.

## 9. Final Comments

Finally, we owe great thanks to our hosts for an exceptionally well-organized and enjoyable meeting. We also owe great thanks to all the presenters and their collaborators for their efforts.

Charm remains a fascinating and vibrant area of research, one with the potential to teach us new things and be hotly pursued in many places.

## References

1. Quoted from his oral presentation at CHARM 2010.
2. Proposal Number 986 - "Medium-Energy Antiproton Physics with The Antiproton Annihilation Spectrometer (TApAS)." See link from the Fermilab PAC web page: [http://www.fnal.gov/directorate/program-planning/phys\\_adv\\_com/PACdates.html](http://www.fnal.gov/directorate/program-planning/phys_adv_com/PACdates.html)
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